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The collembolan fauna of two coal shale tips in north-west England

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1. Introduction

Coal shale often weathers to form an acid substrate and it may be high in toxic elements and low in nutrients. Consequently revegetation of coal shale, although desirable for aesthetic and health reasons, may be a difficult process. Local Authorities in north-west England adopt fertilizing and liming reclamation techniques wherever possible since these are inexpensive when compared with the costs of transporting and spreading topsoil (Bradshaw & Handley 1972). Lancashire County Council Planning Department set up experimental plots on different coal shale heaps to determine the most successful lime, fertilizer and vegetation treatments before full scale grading and planting are undertaken.

This paper reports the results of a preliminary comparison of the collembolan fauna from such experimental plots on two coal shale heaps, one with acidic untreated shale and the other with coal shale nearly neutral in *p*H value. The fauna was compared with the fauna from the "stages of reclamation" proposed by Dunger (1969) and Luff & Hutson (1977) from their studies of reclaimed land and with species sampled from land adjacent to both sites. This preliminary sampling was later followed by more detailed studies of the Acari (Luxton 1982), Pauropoda (Moore 1982) and Collembola (Moore & Luxton in prep.) from the acidic site.

2. Site descriptions

2.0. General remarks

Two coal shale heaps were sampled. The Welch Whittle site had coal shale with a high concentration of acid-producing pyrite which caused the untreated shale to have a *p*H as low as 2.7. With the addition of the basic shale limestone treatment, shale *p*H was raised to 4.4 while the experimental liming treatment further raised the shale *p*H to 5.9. The untreated coal shale at the Pennington Flash site was nearly neutral with *p*H values of 6.5 to 7.5.

2.1. Welch Whittle

This site is located at National Grid Reference SD 5413. The coal shale heap covers 10 ha adjacent to the M 6 Motorway approximately 2 km south of the Charnock Richard Service Station. Mining ceased at Welch Whittle in 1960 and in 1968 and 1969 alder saplings (*Alnus glutinosa* Gaertn.) were planted and 64 kg ha^{-1} grass seeds mixture (consisting mainly of *Lolium perenne* L.) was sown. This reclamation programme met with only limited success and large areas of total failure of recolonisation occurred. The alder trees survived only on the lower, moister areas of the shale heap. In 1972 experimental plots (each 4 m × 1.25 m) were established for field trials of grass maintenance under different clover, liming, nitrogen and grass cutting regimes. Plots were paired, separated by bare shale and situated on the east facing slope of the coal shale heap.

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Each plot received a basic shale treatment of:

10,000 kg ha-ground limestone incorporated into the shale;
150 kg ha^{-1} P_2O_5 as superphosphate;
50 kg ha^{-1} K_2O as sulphate of potash;
100 kg ha^{-1} urea;
100 kg ha^{-1} grass seeds mixture (80% *Festuca rubra* L., and 20% *Agrostis tenuis* SIBTH.).

The experimental treatments allocated to the plots were:

(1) Clover
(a) 20 kg ha^{-1} *Trifolium repens* L. in the grass seeds mixture;
(b) no clover.

(2) Liming
(a) 10,000 kg ha^{-1} ground limestone applied as a top dressing on April 13th 1973;
(b) no additional limestone.

(3) Nitrogen
(a) 100 kg ha^{-1} nitrogen as urea added to the plots on April 13th 1973 and May 30th 1974;
(b) no additional nitrogen.

(4) Grass cutting
(a) grass cut and removed from the plots in late autumn 1973 and 1974;
(b) no cutting, grass allowed to die back.

The grass seeds mixture was sown on August 11th 1972 and a maintenance treatment of 150 kg ha^{-1} P_2O_5 was added in December 1972 to all the plots.

2.2. Pennington Flash

This site is located at National Grid Reference SK 6399. The coal shale heap is 2.5 km to the south-west of Leigh. It is bounded on its southern and eastern sides by a lake, on the northern side by a canal and on the western side by the A 578 road. Experimental plots were established in 1972 to investigate grassland growth under different nitrogen and grass cutting regimes. Fourteen 10 m × 2.5 m experimental plots were located in 2 blocks of 7 plots on the north-facing slope of the shale heap. These all received the following basic shale treatment:

2,500 kg ha^{-1} ground limestone incorporated into the shale;
100 kg ha^{-1} K_2O as sulphate of potash;
125 kg ha^{-1} P_2O_5 as superphosphate;
100 kg ha^{-1} grass seeds mixture (60% *Lolium perenne* L., 30% *Festuca rubra* L. and 10% *Agrostis tenuis* SIBTH.) sown on May 9th 1972.

The different experimental applications of nitrogen were not recorded. Plots either had the grass cut and removed annually or the grass was allowed to die back *in situ*. Maintenance treatments later applied to all plots were:

125 kg ha^{-1} P_2O_5 in November 1972 and in November 1973;
125 kg ha^{-1} nitrogen as urea on April 17th 1973;
62.5 kg ha^{-1} nitrogen as urea on April 8th 1973.

3. Materials and methods

For this preliminary study the sites were sampled as indicated in Table 1 (Welch Whittle) and Table 2 (Pennington Flash). Each shale core was 0.01 m^2 in area and 3 cm in depth and the vegetation above the core was also collected (these individual samples are referred to as "units" in the Tables). The animals were extracted from the shale cores with a Tullgren funnel over a period of 84 h with a maximum temperature of 52 °C above the sample. The vegetation sample units were confined in a stainless steel funnel and a lamp was placed at the funnel mouth as a heat and light source for 54 h. The animals were collected in a 10% aqueous solution of picric acid then preserved in absolute ethanol.

4. The collembolan fauna

4.1. General remarks

Twenty species of Collembola were recorded from the experimental plots but only five of these occurred on both sites (Tables 1 and 2). Many of the recorded collembolan densities were within the $5—50 \times 10^3$ m^{-2} range typical of collembolan populations (HALE 1967), although population densities greatly in excess of this also occurred. High densities of Collembola on newly reclaimed and artificially sterilized soils have been recorded by other

workers (Baweja 1939, El-Kifl *et al.* 1974, Nijima 1976, Lawrence & Khaloyan 1977, Hutson 1980) and these were thought to result from low numbers of predatory mesostigmatid mites and other arthropods (Luff & Hutson 1977). Few mesostigmatid mites were found on the north-west coal shale except on the "cut: lime: nitrogen: no clover" plot at Welch Whittle and the topsoiled plot at Pennington Flash, where they formed 24% and 80% of the mite abundances respectively (Luxton 1982). Lower collembolan population densities were recorded in these plots.

4.2. Welch Whittle

Mesaphorura atlantica Rusek, *Isotoma viridis* Bourlet and *I. grisea* Lubbock were dominant on the Welch Whittle experimental plots on November 4th 1974 while *I. notabilis* Schäffer was dominant in the grass cut from the plots on April 23rd 1975 (Table 1). *Proisotoma minuta* (Tullberg), although not recorded from the experimental plots, was dominant in the grassland soils adjacent to the coal shale heap. *M. atlantica* and *I. notabilis* were dominant in the revegetation established in the 1968/1969 reclamation programme. The highest collembolan density at Welch Whittle occurred on the "no cutting: no lime: nitrogen: clover" plot (278,500 m^{-2}). Lower densities were recorded from the revegetation from the 1968/1969 reclamation programme (42,467 m^{-2}) and from grassland adjacent to the coal shale heap (14,950 m^{-2}).

4.3. Pennington Flash

Mesaphorura macrochaeta Rusek, *Proctostephanus madeirensis* da Gama, *Cryptopygus garretti* (Bagnall), *I. viridis* and *I. grisea* were the dominant species on the Pennington Flash experimental plots. Different species dominated on the different shale treatments and *Onychiurus armatus* (Tullberg), *Hypogastrura* sp. and *Sminthurus* sp. were collected only from the topsoiled plot (Table 2). *M. macrochaeta*, *C. garretti* and *O. armatus* were dominant in the grassland soil, *M. macrochaeta* and *O. armatus* in the revegetated peat cover, and *M. macrochaeta*, *P. madeirensis*, *I. grisea* and *Hypogastrura* sp. in the natural revegetation. At Pennington Flash the highest collembolan density was recorded from the "no cutting: no nitrogen" plot (59,900 m^{-2}) while similar densities were recorded from the "cut" plot (33,150 m^{-2}) and the "no cutting" plot (33,350 m^{-2}). Population densities recorded from the grassland soil (25,550 m^{-2}) and peat cover on shale (12,400 m^{-2}) were lower than those from the experimental plots. The natural revegetation by the lake was sampled on two occasions. In March 1975 a population density of 26,300 m^{-2} was recorded while in May 1975 the density had increased to 121,000 m^{-2}.

4.4. Concluding remarks

Several of the collembolan species sampled from the north-west sites were important colonizing species of other newly-reclaimed and sterile areas (Table 3). *Isotoma sensibilis* Tullberg, *Tomocerus longicornis* (Müller), *T. minor* (Lubbock) and *P. madeirensis* recorded from the north-west sites were not found on coal shale sampled in Co Durham (Hutson 1980) or in the German Democratic Republic (Dunger 1968, 1978). However, Hutson (1980) removed the vegetation from the sample units before extraction and would therefore have lost some surface dwelling species. Reclamation sites may also harbour unusual species of Collembola. *Mesaphorura atlantica* was originally described from material collected at Welch Whittle (Rusek pers. comm.) and *Proctostephanus madeirensis*, a dominant species at Pennington Flash, had previously only been recorded in Britain on steel slag heaps in South Wales and the mechanism by which it was introduced to Britain is not known (Lawrence & Khaloyan 1977).

5. Discussion

The fauna recorded from the experimental plots at Welch Whittle and Pennington Flash was characteristic of the "colonization stage" of reclamation (Dunger 1969, Luff & Hut-

Table 1. Collembolan species from Welch Whittle

	% dominance from the experimental plot sample units collected on Nov. 4th 1974						% dominance from the sample units collected from land adjacent to the experimental plots on April 23rd 1975										
	A	B	C	D	E	F	1	2	3	4	5	6	7	8	9	10	11
Mesaphorura atlantica Rusek	91	76	14	87	23	.	45	65	69	3	3	11	11	17	.	100	100
Onychiurus latus Gisin							.	.	.	.	1	.	12	.	.	.	.
Onychiurus sp.	.	1	.	.	.	.											
Isotoma viridis Bourlet	8	20	76	8	39	1	2	1	.	8	1	5	.	.	1		
Isotoma grisea Lubbock	1	2	6	3	38	94	.	.	.	.	.	.	2	.	1		
I. olivacea var. stachi Denis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4		
Isotoma notabilis Schäffer							44	29	30	16	9	29	22	10	85		
Isotoma sensibilis Tullberg							.	.	.	.	.	.	.	.	2		
Isotomurus palustris (Müller)							1	4	.	8	.	.	.	.	.		
Proisotoma minuta (Tullberg)							.	.	.	.	82	53	46	65	.		
Lepidocyrtus lignorum Fabricius	.	.	2	1	.	2	6	.	1	40	4	2	1	4	3		
Lepidocyrtus cyaneus Tullberg							1	.	.	12	.	.	.	.	2		
Pseudosinella sexoculata Schött	.	.	1	.	.	.											
Tomocerus minor (Lubbock)	.	.	1	1	.	3	.	.	.	.	.	.	.	.	1		
Tomocerus longicornis (Müller)							.	1	.	.	.	.	6	1	1		
Hypogastrura sp.							1	.	.	13	.	.	.	3	.		
Sminthurides sp.	.	1	.	.	.	.											
Collembolan community density (10^3 m^{-2})	45	31	16	279	1	43	48	20	60	14	43	34	12	18	59	2	1

Sample unit location codes: (A, B, C, D contained both shale and vegetation; E, F contained vegetation only).

(i) experimental plots: A, cut, no lime, no nitrogen, no clover; B, cut, lime, no nitrogen, no clover; C, cut, lime, nitrogen, no clover; D, not cut, no lime, nitrogen, clover; E, not cut, lime, no nitrogen, no clover; F, not cut, no lime, no nitrogen, no clover.

(ii) other samples: 1—3, shale from foot of east slope where vegetation was established in the 1968/69 revegetation programme; 4, alder leaf litter; 5—6 soil and vegetation from grassland beneath alder trees at foot of east slope; 7—8, soil and vegetation from grassland adjacent to the coal shape heap; 9, grass cut from the experimental plots; 10—11, bare shale near the plots.

Table 2. Collembolan species from Pennington Flash

	% dominance from the experimental plot sample units collected on Nov. 4th 1974							% dominance from the sample units collected from land adjacent to the experimental plots											
								March 3rd 1975						May 12th 1975					
	A	B	C	D	E	F	G	a	b	c	d	e	f	1	2	3	4	5	6
Mesaphorura macrochaeta RUSEK	33	32	28	7	6	1	5	34	70	66	66	55	18	2	6	60	.	20	100
Onychiurus armatus (TULLBERG)	.	.	.	.	.	11	.	11	12	25	28	5	11	1	1	.		.	.
Proctostephanus madeirensis DA GAMA	41	55	.	.	84	1	.	.	1	5	.	5	32	95	90	40	100	80	.
Cryptopygus garretti (BAGNALL)	16	4	27	34	.	1	.	27	2			1	3						
Isotoma viridis BOURLET	10	4	19	20	4	61	21	5	4	2	3	12	1						
Isotoma grisea LUBBOCK	.	5	26	37	5	5	69	5	5	.	2	2	22	1	1	.	.	.	.
Proisotoma minuta (TULLBERG)								3	.	.	.	.	.						
Entomobrya sp.	.	.	.	.	1	.	.												
Lepidocyrtus lignorum FABRICIUS	.	.	.	.	.	1	4	4	1	.	1	.	4	.	1	.	.	.	.
Pseudosinella sexoculata SCHÖTT				2	.	.	.												
Tomocerus minor (LUBBOCK)	.	.	.	.	.	.	1												
Hypogastrura sp.	.	.	.	.	.	10	.	11	5	.	.	19	9	1	1	.	.	.	.
Sminthurus sp.	.	.	.	.	.	9	.	.	.	2	.	1	.	.	.				
Collembolan community density (10^3 m^{-2})	40	26	28	38	60	26	11	11	41	6	18	27	25	167	75	1	3	1	1

Sample unit location codes: (A, B, C, D, E contained both shale and vegetation; F contained soil and vegetation; G contained vegetation only).

(i) experimental plots: A, B, cut, nitrogen treatment not recorded; C, D, not cut, nitrogen treatment not recorded; E, not cut, nitrogen; F, topsoiled plot; G, grass from same plot as sample D.

(ii) other samples: a, b, soil and vegetation from grassland adjacent to coal shale heap; c, d, revegetation from the peat cover on the shale; e, f, shale and vegetation from the natural revegation by the lake; 1, 2, shale and vegetation from the natural revegetation by the lake; 3, 4, bare shale by the lake; 5, 6, bare shale by the experimental plots.

Table 3. Pioneer collembolan species colonizing sterile areas

Authority	Locality: Habitat	Species
Davis (1963)	(Corby, England)	
	1. levelled quarry	*Tullbergia krausbaueri* (Börner) *Isotoma viridis* Bourlet
	2. reclaimed grassland	*T. krausbaueri*, *Tullbergia quadrispina* (Börner), *I. viridis*, *Isotoma notabilis* Schäffer, *Lepidocyrtus cyaneus* Tullberg, *Lepidocyrtus curvicollis* Bourlet
Bödvarsson (1966)	(Iceland)	
	1. glacier edge	*I. viridis*
	2. soil after 3 years	*Isotoma sensibilis* Tullberg
	3. soil after 4 years	*T. krausbaueri*, *I. sensibilis*, *I. viridis*, *L. cyaneus*
Wood (1967)	(Malham Tarn, England)	
	1. moss on boulders	*Anurophis laricis* Nicolet
	2. skeletal soil	*I. sensibilis*, *I. viridis*, *I. notabilis*, *Lepidocyrtus lanuginosus* (Gmelin)
Cotton (1967)	(Gower, Wales)	
	1. semi-fixed sand dune	*I. viridis*
Dunger (1968)	(Berzdorf, GDR)	
	1. bare coal shale	*Mesaphorura macrochaeta* Rusek, *Hypogastrura succinea* Gisin, *Entomobrya lanuginosa* (Nicolet), *I. viridis*, *Lepidocyrtus paradoxus* Uzel
	(Böhlen, GDR)	
	1. bare coal shale	*M. macrochaeta*, *Proisotoma minuta* (Tullberg), *Hypogastrura vernalis* (Carl), *Folsomia candida* (Willem), *Entomobrya multifasciata* (Tullberg), *Orchesella quinquefasciata* (Bourlet), *Sphaeridia pumilis* (Krausbauer)
Lindroth *et al.* (1973)	(Surtsey, Iceland)	
	1. sterile land	*T. krausbaueri*, *I. viridis*, *I. sensibilis*
Hutson & Luff (1978)	(Co Durham, England)	
	1. bare coal shale	*Entomobrya albocincta* (Templeton)
Dunger (1978)	(Niederlausitz, GDR)	
	1. bare coal shale	*Hypogastrura assimilis* (Krausbauer), *H. succinea*, *E. multifasciata*, *L. cyaneus*, *Bourletiella hortensis* (Fitch)
Present work	(Welch Whittle, England)	
	1. bare coal shale	*Mesaphorura atlantica* Rusek
	(Pennington Flash, England)	
	1. bare coal shale	*M. macrochaeta*, *Proctostephanus madeirensis* da Gama

son 1977). Hutson (1980) found Collembola and Acari dominated the coal shale fauna in Co Durham (north-east England) although occasionally Hemiptera, Araneida, Thysanura, dipteran larvae, Coleoptera, Diplura, Pauropoda, Symphyla, and Enchytraeidae were also recorded. A similar general faunal association occurred at Welch Whittle and Pennington Flash, although Enchytraeidae were not investigated. No earthworms were found in either the north-east (Hutson 1980) or the north-west coal shale.

Most of the species of Collembola collected from the experimental plots were recorded from the grassland soil and natural revegetation near the plots. Wind dispersal probably accounted for the colonization since wind is an important dispersal agent of Collembola not confined to the soil and humus (Bellinger 1954, Hale 1963, Brahin & Edwards

1964, Lindroth *et al.* 1973). Buahin (1965) demonstrated that Collembola also dispersed by locomotion through the soil and by crawling and jumping above ground to re-invade artificially sterilized plots. Once Collembola have invaded the experimental plots at Welch Whittle and Pennington Flash, movement may occur from plot to plot over the intervening bare shale.

Many microarthropods are tolerant of a wide range of *p*H values, although individual species may show a *p*H optimum (Edwards & Lofty 1974, Hågvar & Abrahamsen 1980). Microarthropod colonization is influenced by *p*H (Hågvar & Abrahamsen 1980) and collembolan reproductive behaviour is also significantly affected (MacLagan 1932, Ashraf 1969, Hutson 1978, Hågvar & Abrahamsen 1980). Luxton (1982) suggested that the *p*H influence on microarthropods of coal shale might also be exerted through its effect on food supply. The two north-west coal shale heaps sampled had different *p*H values and their dominant Collembola and Acari species were different. *Mesaphorura atlantica* and the oribatid mite *Verachthonius laticeps* (Strenzke) were dominant at Welch Whittle, while *Mesaphorura macrochaeta* and the oribatid *Oppiella nova* (Ouds.) were dominant at Pennington Flash (Tables 1 and 2, Luxton 1982).

Environmental conditions on bare coal shale are extreme but once a vegetation cover has become established colonization proceeds rapidly and industrial land is able to support a large and varied fauna within a year of reclamation (Baweja 1939, Hutson 1972, Luff & Hutson 1977). At the "colonization stage" of reclamation there is some incorporation of organic matter into the shale and Collembola are important in litter breakdown (Dunger 1968, Hutson 1974). However, in the present study the harshness of the coal shale environment was indicated by the fact that only one species of *Mesaphorura* was recorded from each of the sampled sites. In developed localities two or more species of *Tullbergia* or *Mesaphorura* often occur together. *Mesaphorura* was dominant at both the north-west coal shale heaps sampled but the persistence of only one species at each site indicates that Welch Whittle and Pennington Flash are both ecologically different and have harsh environments.

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Two coal shale heaps in north-west England, one with acidic coal shale and the other with shale nearly neutral in *p*H, were studied. The invertebrate fauna was extracted from sample units collected from bare shale, from experimental plots, from natural revegetation on the coal shale heaps, and also from adjacent grassland soil. The coal shale fauna was characteristic of the "colonization stage" of reclamation with microarthropods, especially Collembola and Acari, numerically dominant. Wind dispersal probably accounted for colonization of the coal shale experimental plots.

Twenty species of Collembola were recorded but only five occurred on both sites. The highest collembolan population density at the most acid site (Welch Whittle) was recorded from the "no grass cutting: no lime addition: nitrogen added: clover sown" plot (278,500 individuals m^{-2}) and at the more neutral *p*H site (Pennington Flash) from the "no grass cutting: no nitrogen added" plot (59,900 individuals m^{-2}).

Key words: Collembola, coal shale, north-west England, reclamation treatments, colonization.